PEM Research

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Outline

- Temperature limitations in PEMs
- HAST
- Acoustic microscopy
- Wire bond quality
- How to improve PEM guidelines

What limits testing T for PEMs?

- Maximum junction temperature
- Max. operational temperature
- Max storage temperature
- Glass transition temperature of MC

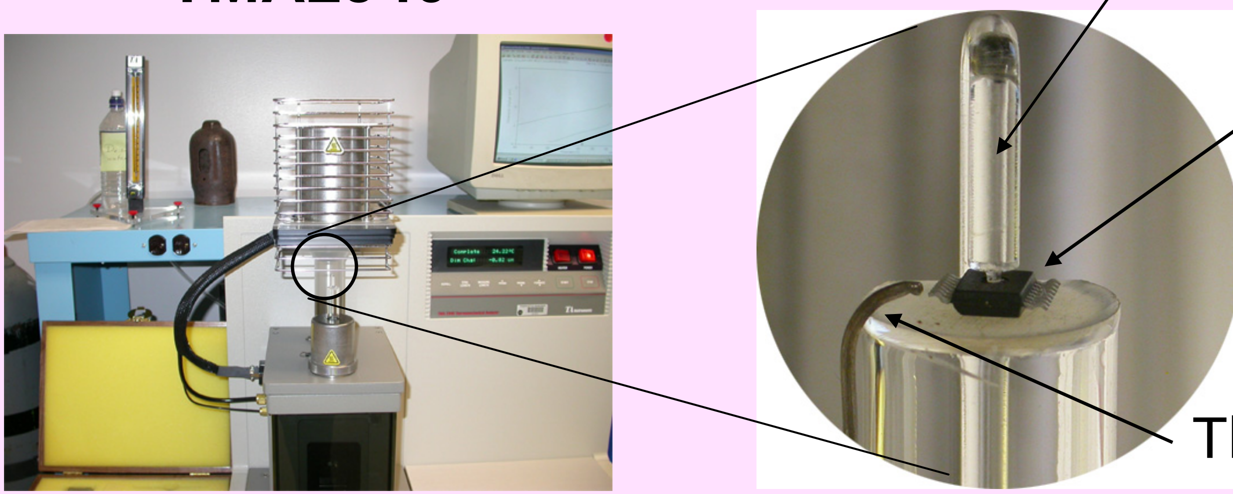
- There is no standardized technique to determine $T_{j\ max}$ and T_{st}(?)
- Absolute maximum ratings?
- Mfrs. warn that exceeding these T may cause permanent damage

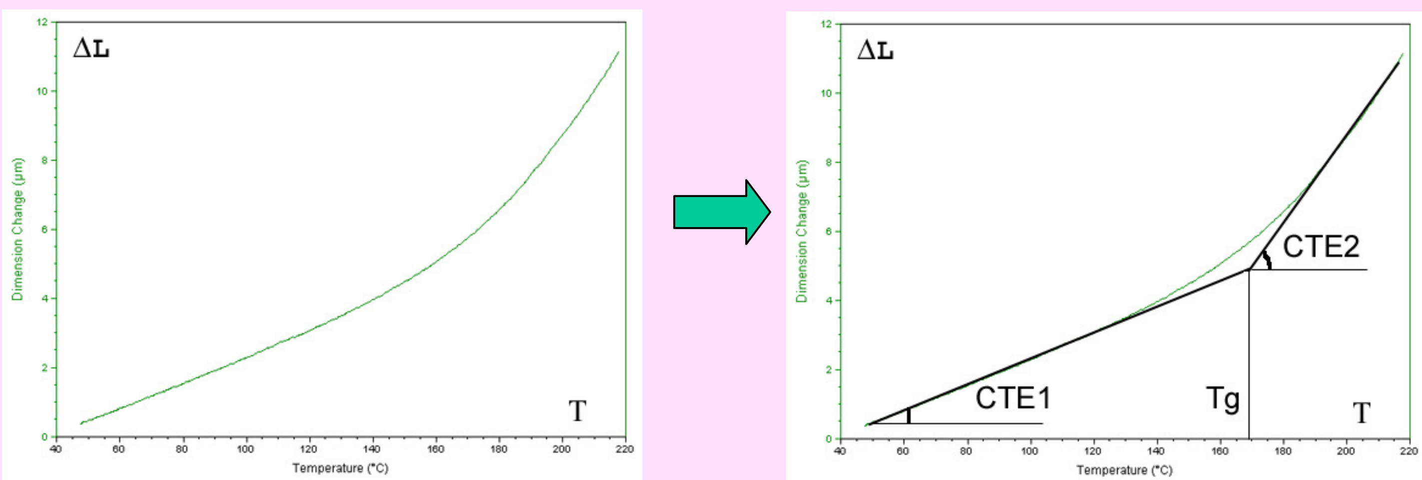
- Ex1: Tjmax=165 ^{o}C, Tst=150 ^{o}C
- Ex2: Tjmax=100 ^{o}C, Tst=100 ^{o}C
- Does exceeding Tg cause failures?

- A methodology to determine BI temperature and conditions is needed.
- Does exceeding Tg cause failures?

Tg Measurements: TMA

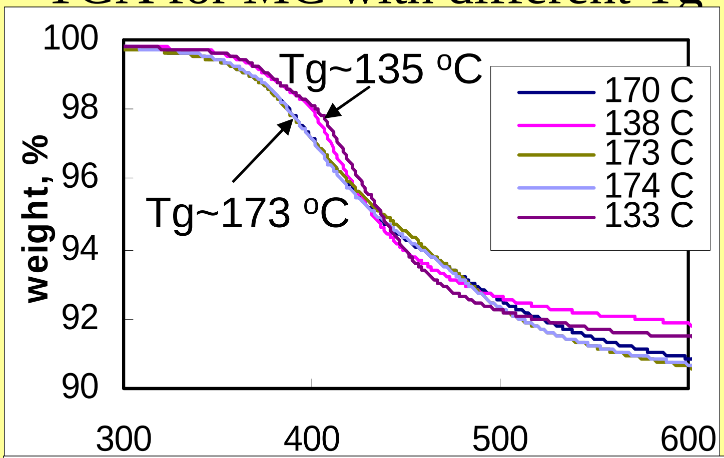
TMA2940

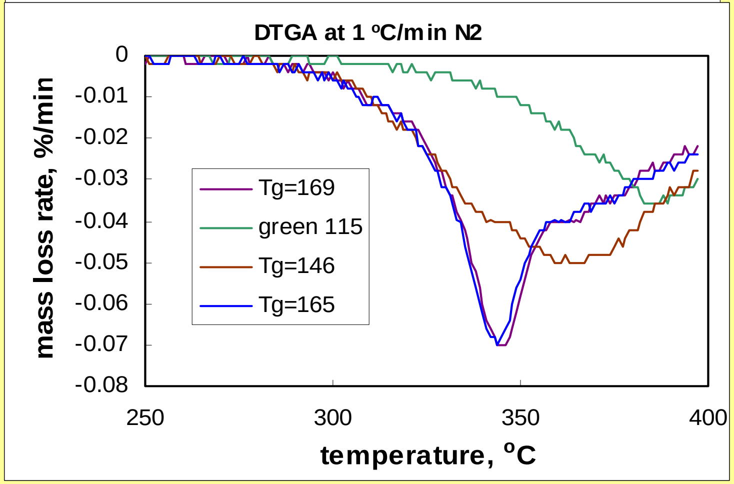




Does low Tg indicate Poor Thermal Stability?

TGA for MC with different Tg

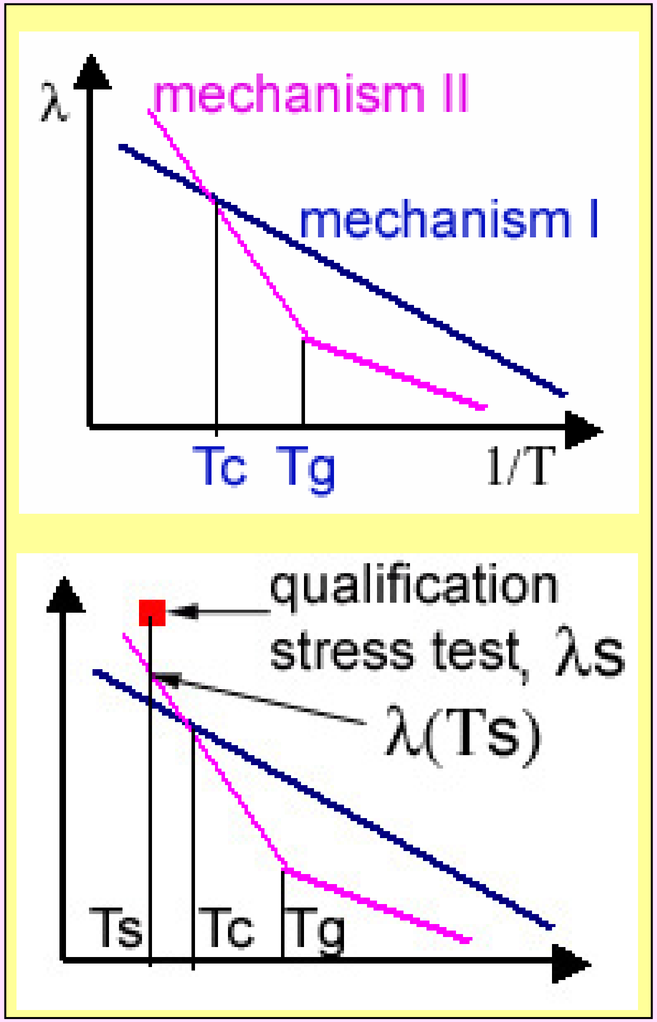




- TGA measurements of MCs with different Tg showed that materials with Tg ~135 and 115 ºC had higher stability compared to MC with Tg.
- The most thermally stable polymers, silicone rubbers and Teflon, have extremely low Tg of -20 to -120 ºC for the rubbers and -90 ºC for Teflon.

Tg is not an indicator of thermal stability of MC

Effect of Tg on Failure Modes and Mechanisms



When characteristics of MC affect reliability of PEMs, the Tg effect might be expected.

This is important for analysis of acceleration factors and for prediction of long-term reliability based on high-temperature stress testing.

Most probable case:
Ts > Tc > Tg; λq >> λexper

Tg most likely will not affect results of standard S&Q testing

Tg Effect Summary

- Changes in failure rates at T>Tg are possible and should be considered for analysis of acceleration factors and prediction of long-term reliability of PEMs based on high-temperature stress testing.
- Experimental data did not reveal the effect of Tg on results of standard screening and qualification testing.
- For a normal quality lot there is no immediate danger in exceeding Tg during standard reliability testing.
- TMA of plastic packages has been proven to be an important tool for FA and reliability evaluation of PEMs.

HAST

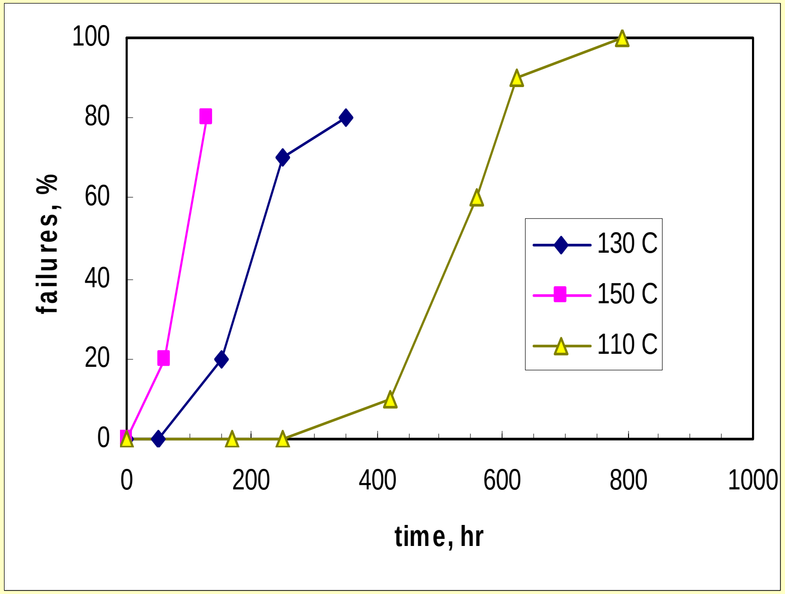
- Biased HAST is the most sever environmental test (~ 30% to 50% chance of failure)
- Is HAST adequate to normal conditions? (130 ^{o}C > Top, swelling, delaminations, acceleration: 100 hr → >100 years)
- Biased HAST → win-win testing for space applications?
- Still… moisture can penetrate to die and cause failures.
- Moisture concentration depends mostly on RH, not on T. Temperature significantly accelerates penetration.
- Unbiased HAST might not reveal moisture-related failures.
- We do need an adequate accelerated testing to assess the effect of moisture for space applications.

Opamp SMT simulation and HAST results

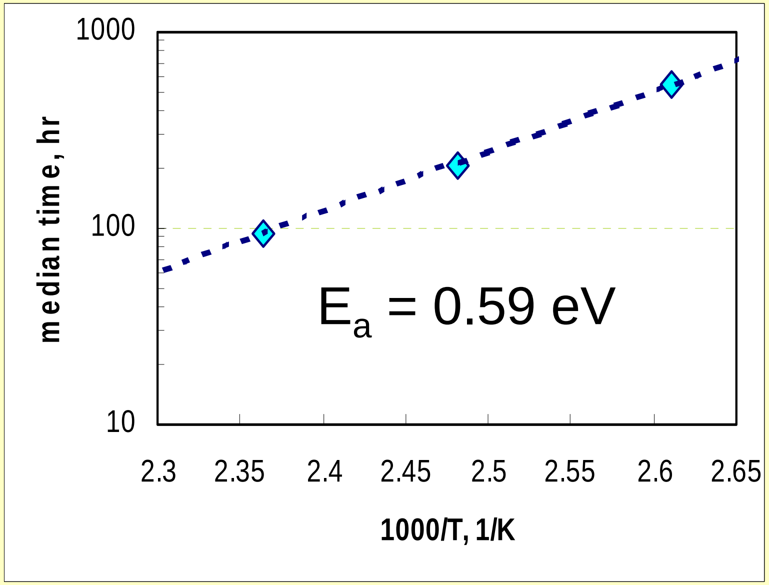
Part	Type	Pack	DC	SMT	HAST	Comm.
OP1	Instr.	SOIC8	0030, 0110	**1**/30, 0/30	**30**/30, **27**/30	Param. failures
OP2	Quad	SOIC16	0101	**16**/30	**2**/30	SMT: IOS and AOL HAST: init.+1 new
OP3	Instr.	SOIC8	0022, 9628	0/16, 0/16	0/16, 0/16	
OP4	Bandw	SOIC8	0018	0/30	0/30	
OP5	Bandw	SOIC8	0041	0/30	0/30	
OP6	Dual	SOIC8	0033, 0109, 9946	0/30, 0/30, 0/30	0/30, 0/30, **1**/30	Possibly reverse installation
OP7	Precis.	SOIC8	0019, 0021, 0029	0/30, 0/30, 0/30	0/30, 0/30, 0/30	
OP8	Quad	SOIC16	9945	**2**/30	0/28	

Distribution of Biased HAST Failures

Failures during biased HAST

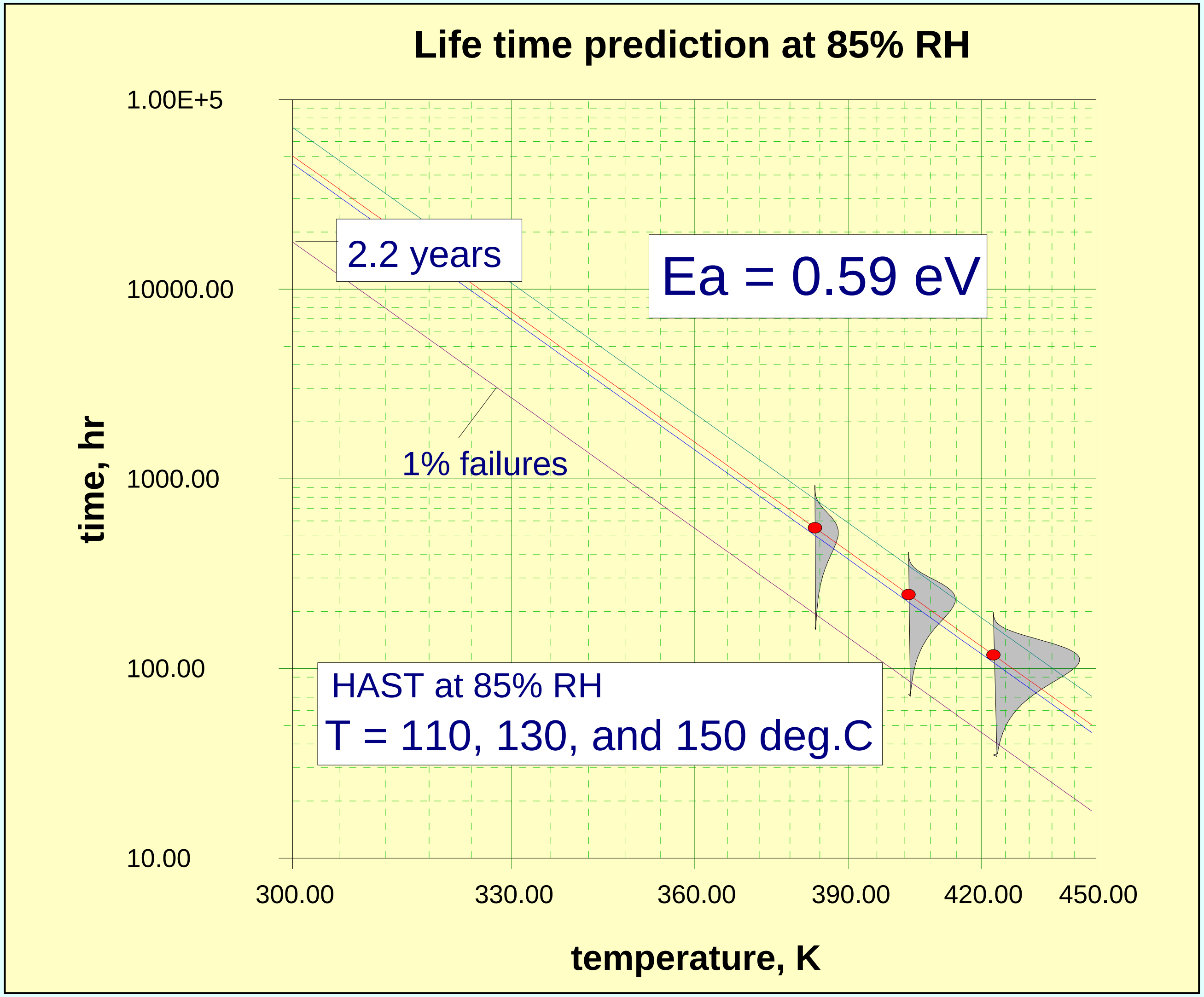


Arrhenius plot of median life



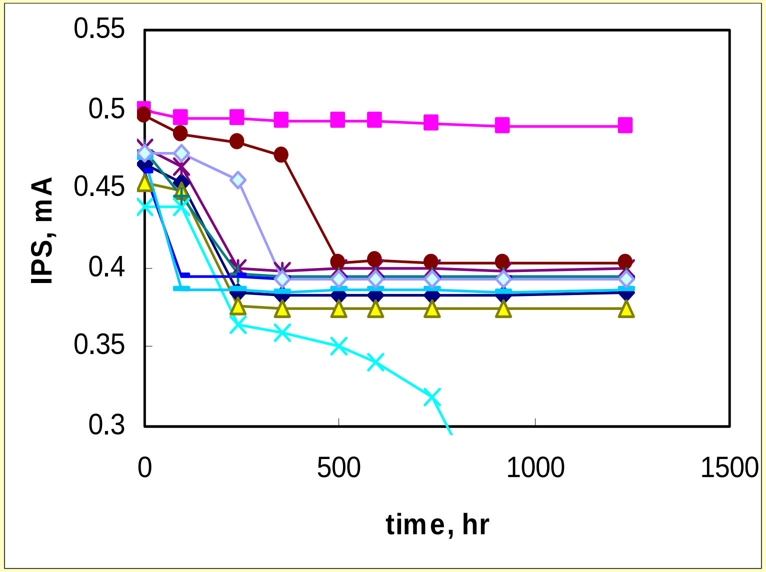
- Ea is lower than in Peck-Hallberg model: 0.79 -1.1 eV.
- This increases the probability of failures at low T.

Arrhenius-Weibull model

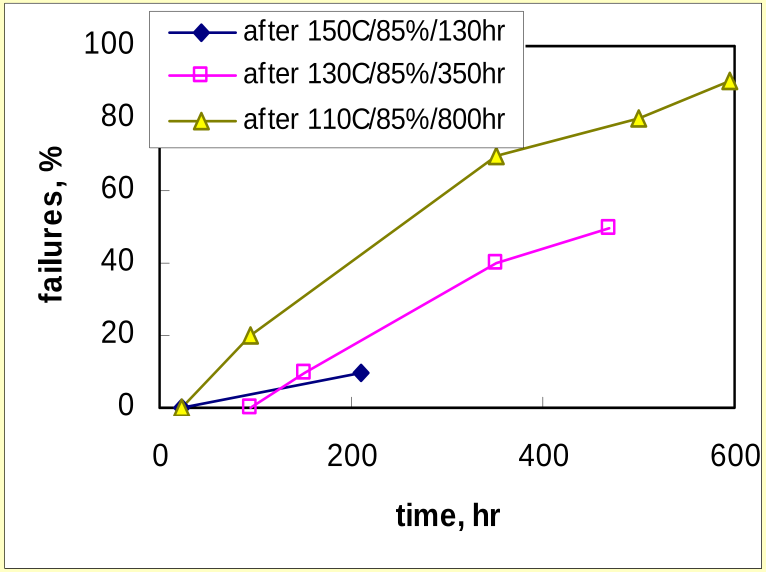


RT Testing after Unbiased HAST

RT bias testing after
110 ºC HAST for 800 hrs

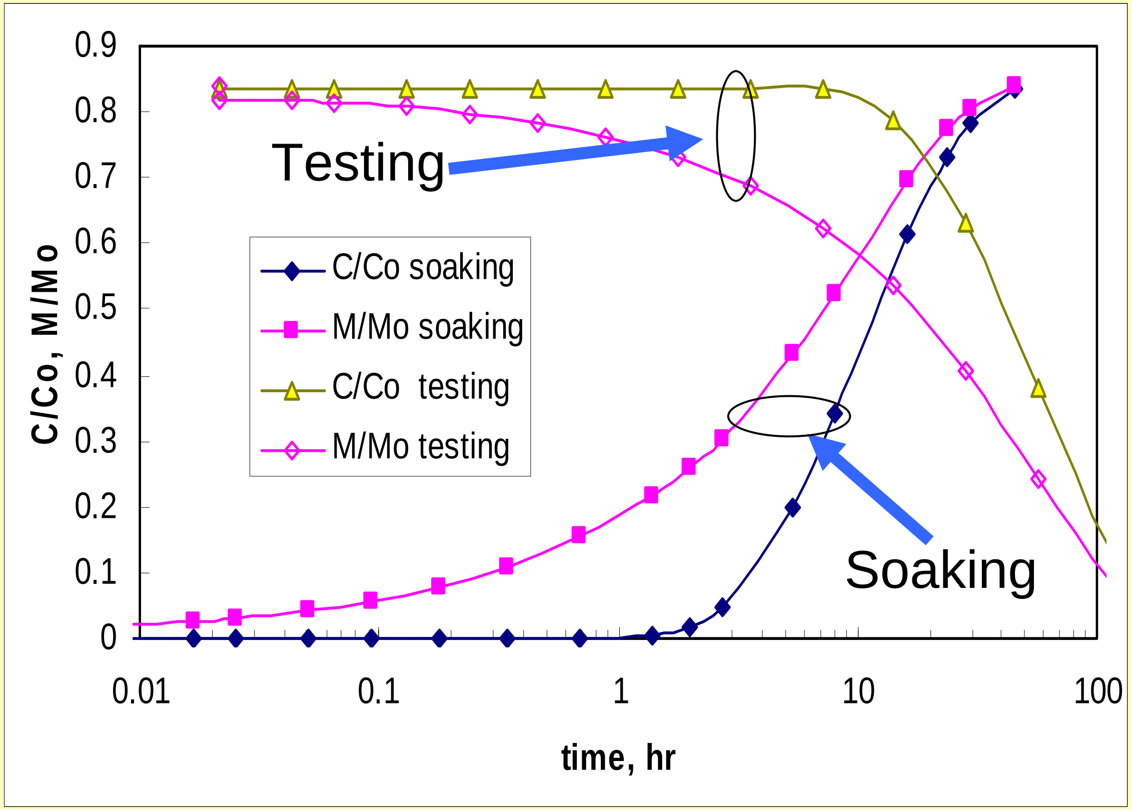


Failures during RT testing
followed unbiased HAST



- RT testing followed unbiased HAST resulted in failures in 24 to 600 hours.
- PEMs retain moisture for some time after HAST.

Moisture diffusion and retention in PEMs



Example:

- Package 2mm
- Soak conditions: 110^{o}C/85%/48hr, unbiased.
- Test conditions: 85 ^{o}C, bias.

Note: C - moisture concentration on the die surface;
M - mass of moisture in the package;
$C/C_o = 1$ corresponds to moisture saturation at 100% RH.

HAST Summary

- Biased HAST is a too severe test for space applications.
- Unbiased HAST is far less severe and might not reveal failures. However, post-HAST testing at RT under bias causes failures.
- A combination of unbiased HAST with LT bias testing might be a good alternative to biased HAST for QA of parts intended for space applications.

C-SAM: SWIFT Statistics

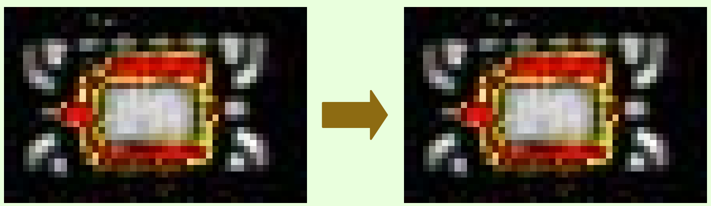
- Rejectable delaminations were observed in 4 out of 6 types of power devices and in 14 out of 23 types of linear devices.
- The proportion of rejects varied from 2.3% to 28% for power devices and from 0.14% to 83% for low-power devices.
- The cost of AM is relatively high, up to $8 per part, even for a large quantity lot.
- Out of 31,090 parts subjected to screening, 565 (1.8%) were rejected by electrical testing and 3,586 (11.5%) by CSAM.

- Acoustic microscopy rejected far more parts than did electrical measurements.
- Are all these rejects potential failures, and if so, what is the confidence in quality of a lot with ~10% rejects?

CSAM: Which Part to Choose?

Delaminations are due to stress relief in PEMs.

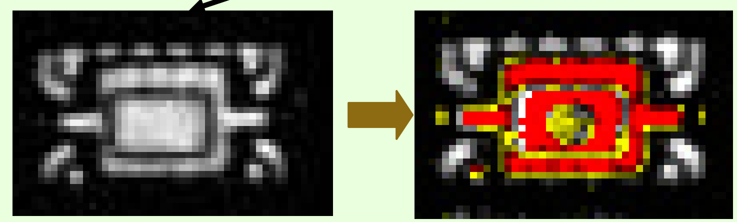
Typically rejected



Before stress. After stress?

This part might operate reliably because mechanical stresses have been relieved and delaminations are stable.

Typically accepted



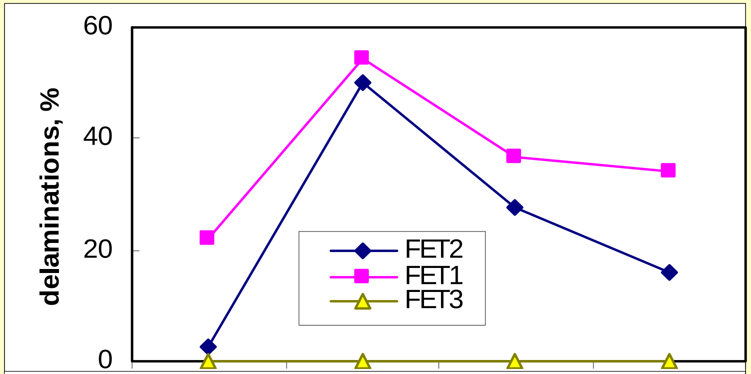
Before stress. After stress?

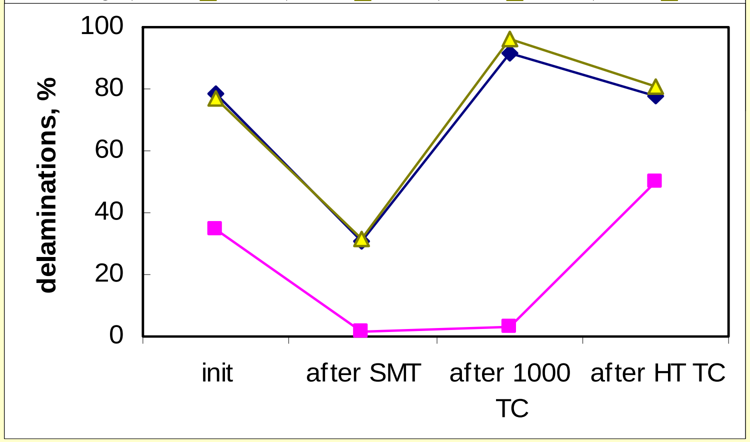
This part might fail if the stresses have not been relieved and delaminations develop in critical wire bond areas.

- CSAM is a nondestructive test, but can damage the parts.
- If delaminations are serious defects, is it possible to improve reliability of a lot with 5% to 50% rejects by screening?
- Is CSAM useful for screening?

Changes in Delaminations Due to Stress Testing (Power Devices)

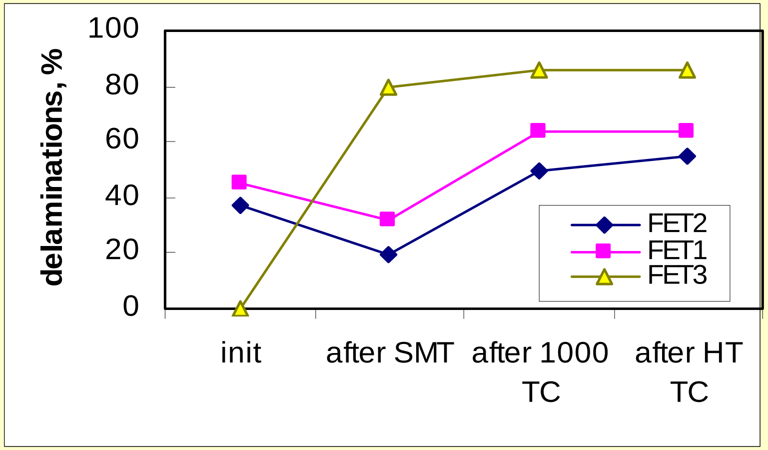
Die surface





Top paddle

Leads



The proportion of delaminations can vary significantly after solder reflow and environmental stress testing

Results of Temperature Cycling of Parts with Excessive Delaminations

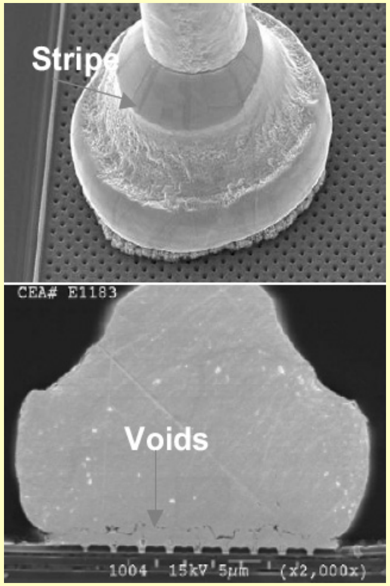
Part	SMT	TC0 100	TC0 300	TC0 1k	TC1 300	TC2 300
PEM1	0/30	0/30	0/30	0/30	0/15	0/15
PEM2	0/30	0/30	0/30	0/30	1/15	1/15
PEM3	0/30	0/30	0/30	0/30	0/15	0/15
PEM4	0/30	0/30	0/30	0/30	0/15	0/15
PEM5	0/30	0/30	0/30	0/30	0/15	0/15
FET1	0/30	0/30	0/30	0/30	0/15	0/15
FET2	0/30	0/30	0/30	0/30	0/15	0/15
FET3	0/30	0/30	0/30	0/30	0/15	0/15
PEM6*	0/30	0/30	0/30	0/30	-	-

*Parts had excessive delaminations at finger-tips after HAST.

CSAM Summary

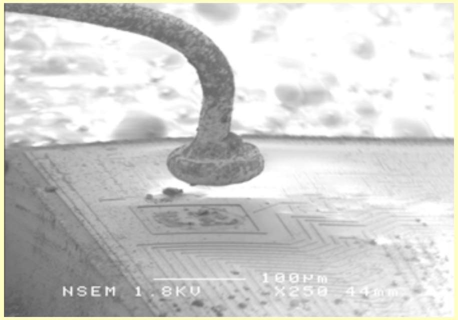
- Parts with excessive delaminations at the paddle and leads (at secondary bond locations) had no electrical failures after 1000 TC at –55 to +125 ^{o}C conditions.
- The analyzed power devices in TO220-style packages are prone to formation of top-of-die delaminations; however, no wire bond fractures occurred even after multiple temperature cycling.
- No correlation between the proportion of delaminations and flux-induced leakage currents were observed indicating a failure of CSAM examination to screen out potential failures.
- For the part types used, CSAM examination likely is not a value-added technique for screening; however, it is very useful for qualification testing.

Wire Bonding: problems recognized by manufacturers



R.Sampan, R Kuang (Actel), CMSE'03:

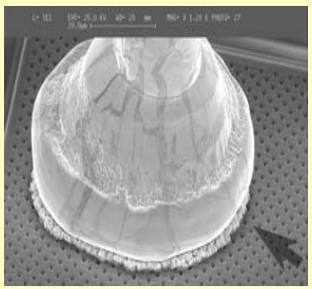
Hermetic gold bonded devices with contamination on bond pads <u>may pass bond pull test at as-bonded condition but fail after 80 hrs at 150°C.</u>



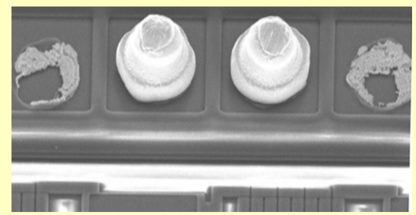
Lifted bonds in various SOIC-type (14/16/20/24 pins) widebody package parts assembled by NSEM between Feb and Nov 2002

Degradation and failures in poor quality wire bonds might happen with time even at relatively benign storage conditions.

Wire Bonding: examples of previously previously revealed problems



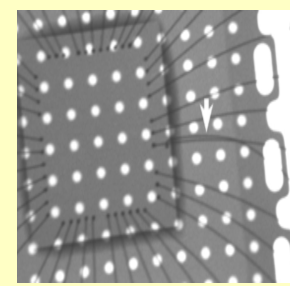
Failures in parts manufactured in 1999 were observed during board-level testing in 2002 (FA: contamination-induced WB degradation).



COTS FPGA failed DPA due to poor wire bonding (2003).

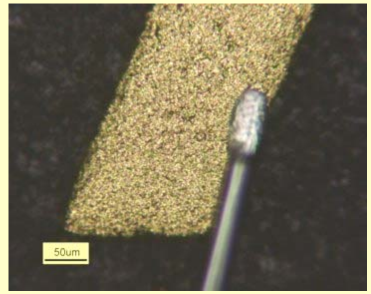
A detector failed in 2002, three years after manufacturing due to degraded WB (Al wire to Au post).

A lifted wire in an ASIC packaged in PQFP was revealed during failure analysis (2003).

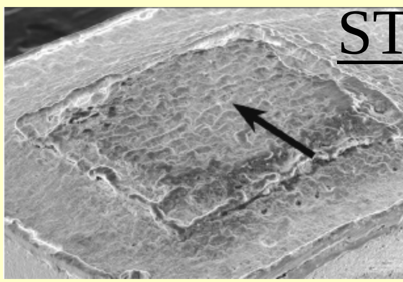


Wire Bonding: problems 2004

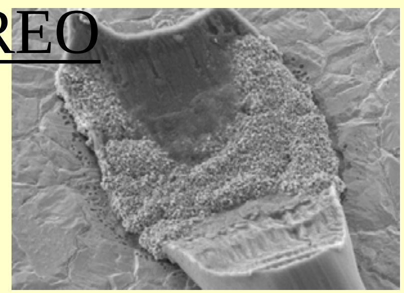
<u>SDO:</u>
MTK-WCG-DF-0412
ASIC ceramic package
Lifting at 1.9 g.



<u>STEREO</u>

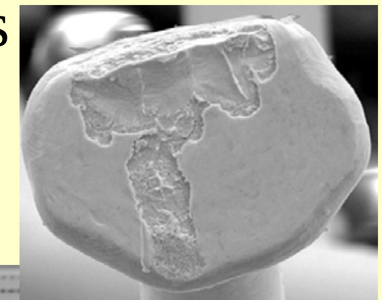


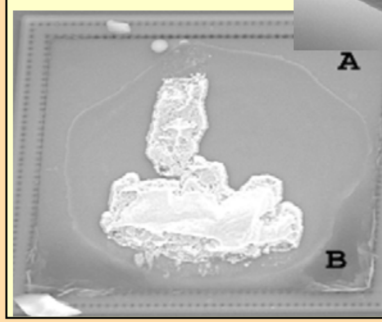
VMI hybrid plastic



XA-16 ASIC ceramic

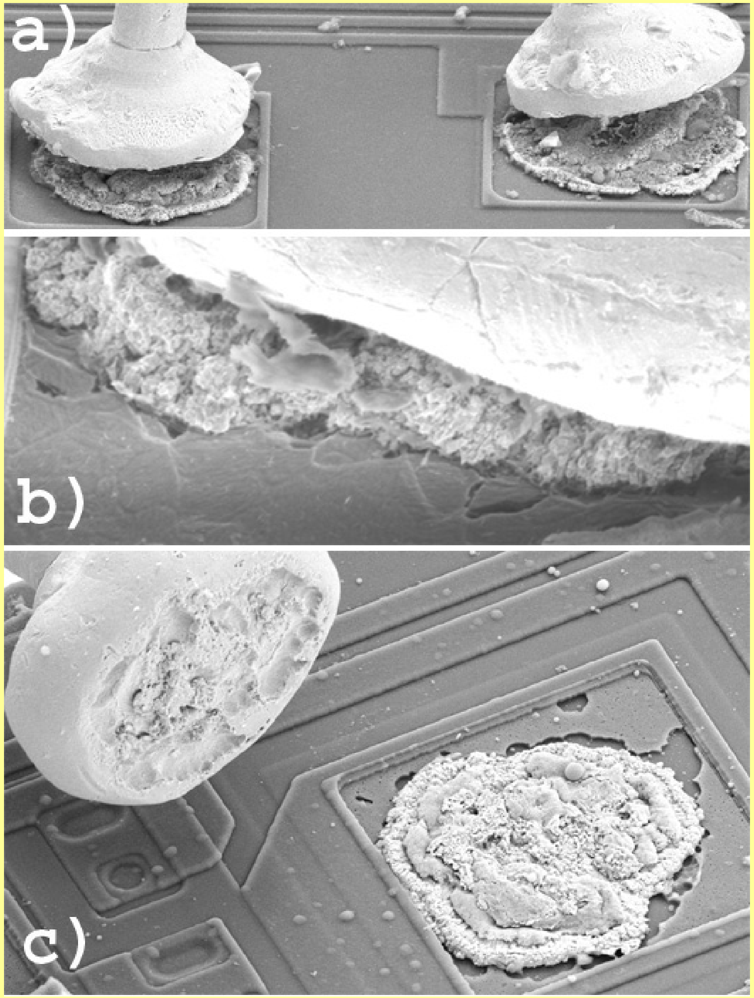
<u>GLAST</u>: photodiodes+
all ASICs
in plastic
QFP





- Substantial portion of reliability issues are now at the packaging level.
- Development of a non-destructive technique for WB qualification in PEMs is important.

Examples of WB degradation after HTSL



- **Most WB were lifted showing porous structure of intermetallics.**
- **The peripheral area of Al around the bonds had multiple voids.**
- **The appearance of voids suggested diffusion of Al atoms towards the WB along the crystalline grain boundaries.**
- **For LT the appearance of the voids suggested a corrosion attack (possibly H_3C-Br).**

Technique for Evaluation of WB Quality

Rc measurements:

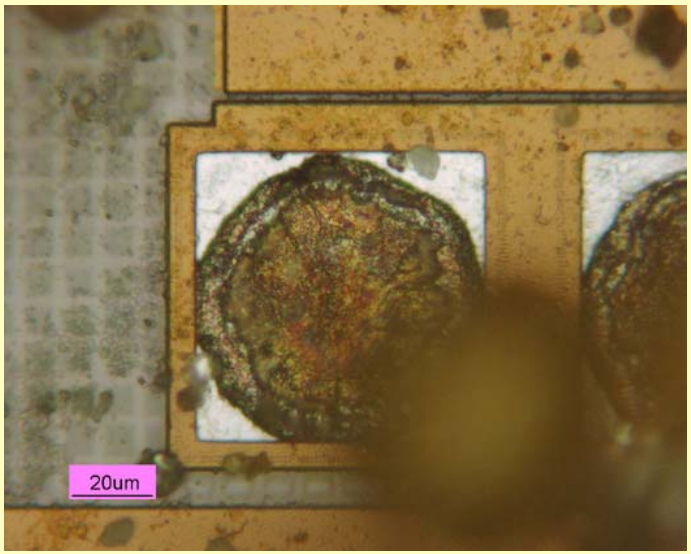
VF of P-N junctions used in the input/output ESD protection circuits are measured before and after the stress

Measure VF_0 → Stress → Measure VF_1

$\delta Rc = (VF_1 - VF_0)/IF$

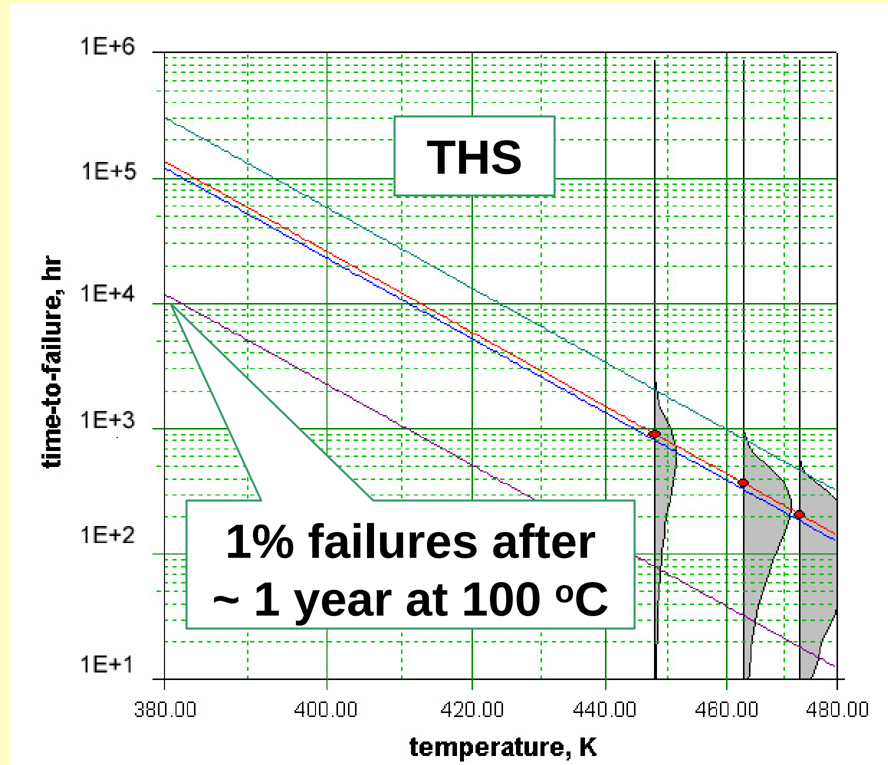
This technique is simple, does not require full electrical characterization, and have an accuracy ~ 0.3 Ohm.

Example of early WB failures



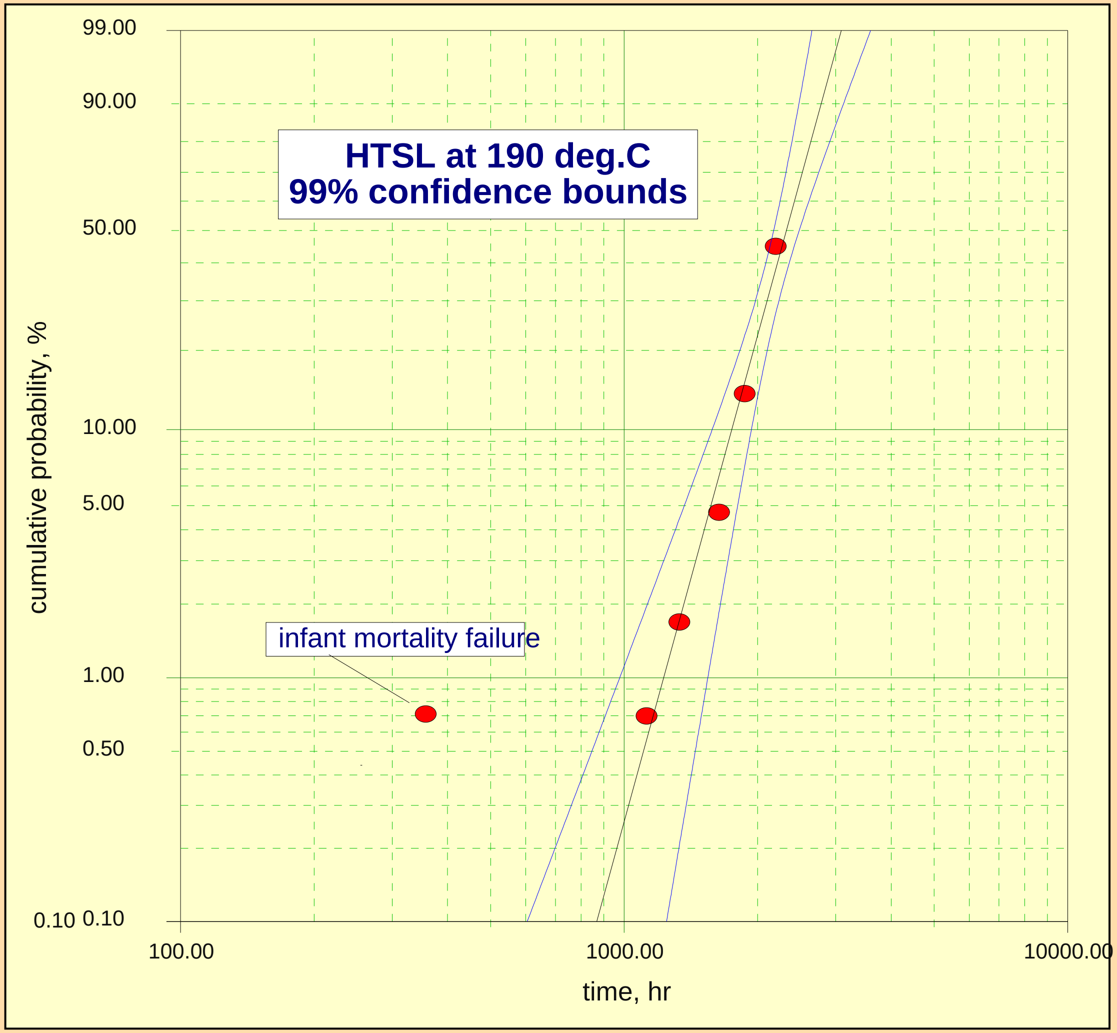
FA results: failures were due to WB degradation

Weibull-Arrhenius plot

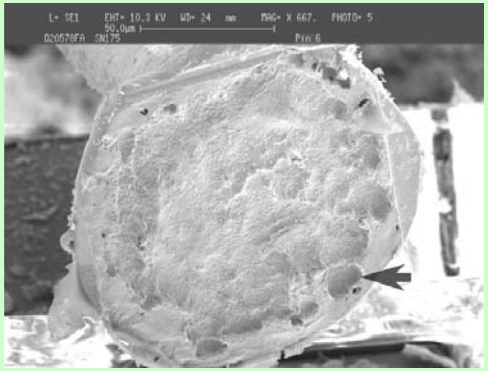


Wire bond degradation might cause failures even at relatively low temperatures of ageing

WB Infant Mortality Failures

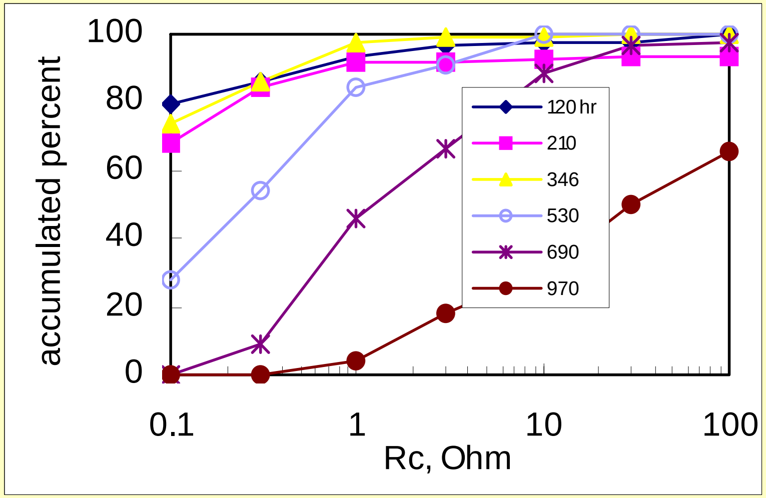


This part had also WB failures after HAST

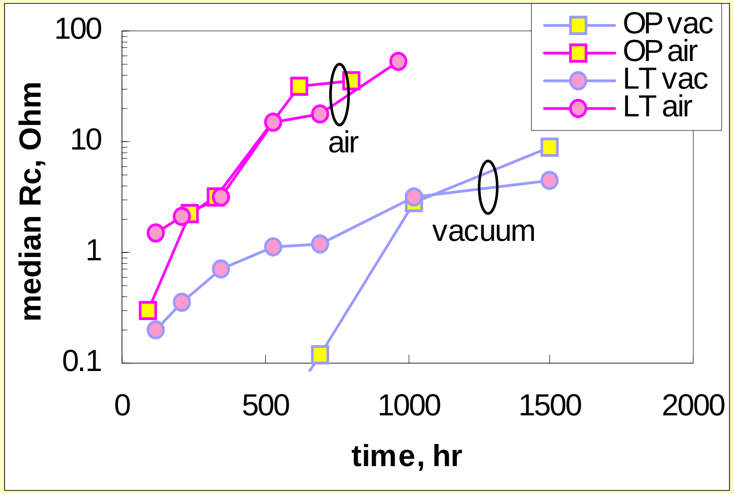


Degradation of contact resistance

Distributions of Rc in air



Kinetics of Rc variations



- **WB degradation in vacuum is much lesser than in air.**
- **After ~1000 hrs in air ~70% of WBs had Rc >10 Ohm; in vacuum Rc < 3 Ohm even after 1500 hrs.**

WB problems: Summary

- WB degradation limits HT reliability of PEMs
- WB is a real problem; however, it is not addressed in the guidelines.
- Forward voltage drop measurement technique might be useful for WB qualification, life prediction and revealing IM failures.
- There is a critical temperature, after which the rate of WB failures changes.
- Vacuum testing might provide high acceleration without introducing new failure modes.

Evolution of Parts Engineering for PEMs

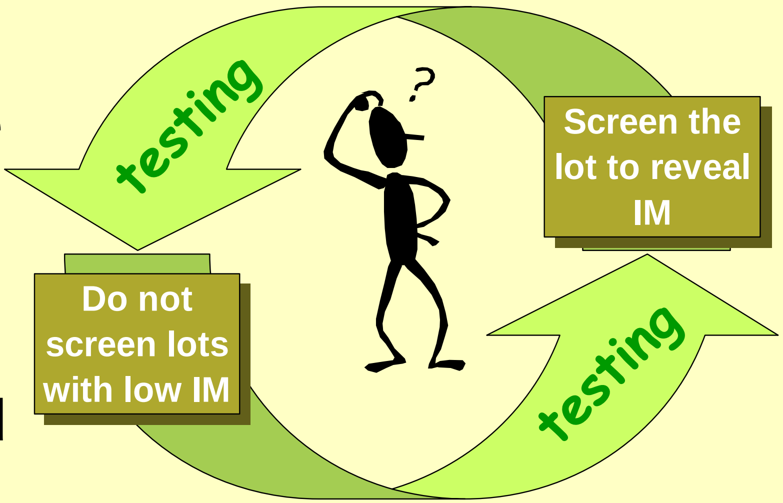
Rule-based (MIL parts) → Phase I, II, .. → **Knowledge-based (COTS PEMs)**

❑No wear-out, no damaging testing. ❑Reliability is mostly limited by defects => the importance of infant mortality and screening.	❑Element and package size reduction → easier to damage. ❑Reliability is limited by intrinsic wear-out mechanisms => **qualification is more important than screening**.
Government maintains the standards and is responsible for reliability provided all criteria are satisfied.	PEs are responsible for reliability evaluation and mitigation of risks associated with use of COTS PEMs.

Catch-22 in Screening

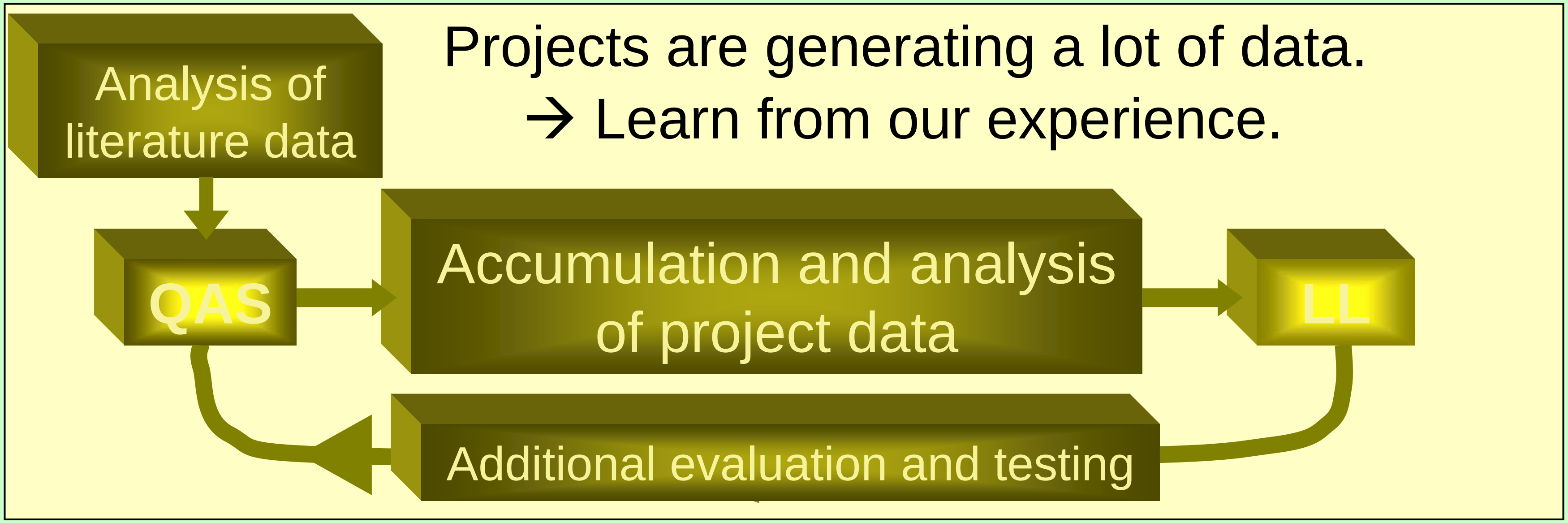
Literature data and our experience:

- Screening might not add value and might negatively impact reliability of high-quality components.
- However, for low-quality components, screening should be maintained.



- To break this circle, make BI and CSAM optional, depending on results of extended qualification.
- Perform qualification on unscreened samples with interim measurements and let the parametric/functional failures to go through. This will identify possible failure modes, evaluate the risk of failures, show whether the screening is necessary, and reduce overall S&Q costs.

A Feedback System to Improve S&Q



- Most project test data are wasted; obtaining statistics of failures is not easy. (Projects are often not concerned about failures <PDA)
- Test results might be deceptive. (Rejects might be due to poor electrical measurements and/or damage during testing.)
- FA results might be insufficient. (FA might be performed only to mitigate the risk for the mission.)
- Do not miss an interesting failure case (WB infant mortality)

Revision of PEM Guidelines

- Make CSAM optional provided extensive qualification using acoustic microscopy is planned.
- Allow qualification of non-screened devices provided a larger quantity of parts with interim measurements, failures going through, and analysis of failed parts, is performed.
- The proportion of area where intermetallics at Au/Al wire bond are formed should be evaluated during DPA. If < 50 %, additional evaluations is necessary (WB package-level qualification).
- Remove Tg limitations for BI.
- Eliminate flux application during preconditioning.
- Replace HAST with a combination of HAST and biased testing at RT.

Some Trends for Improvement of the Guidelines to Discuss in Future

- Put more emphasis on evaluation rather than on DPA. Addressing concerns rather than rejecting suspicious parts.
- More attention to qualification rather than to screening.
- Replace existing 3-level S&Q test flows with specially designed application-dependent plans.
- Use alternate techniques for S&Q:
  - noise measurements;
  - Non-linearity
  - Rc measurements for WB qualification.
  - Thermal impedance for power devices.
  - …